Stochastic Look-ahead Dispatch with Intermittent Renewable Generation

via Progressive Hedging and L-shaped Method

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June 25th, 2014

Contents

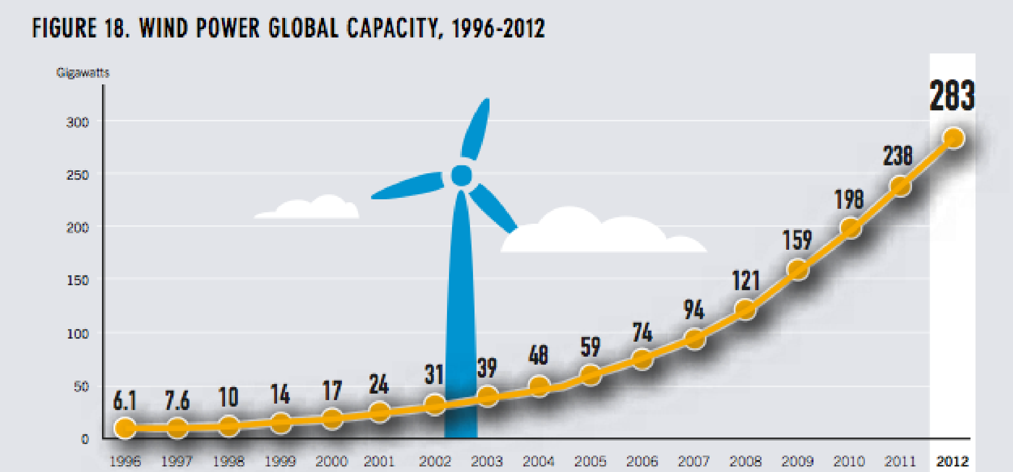
Key Questions

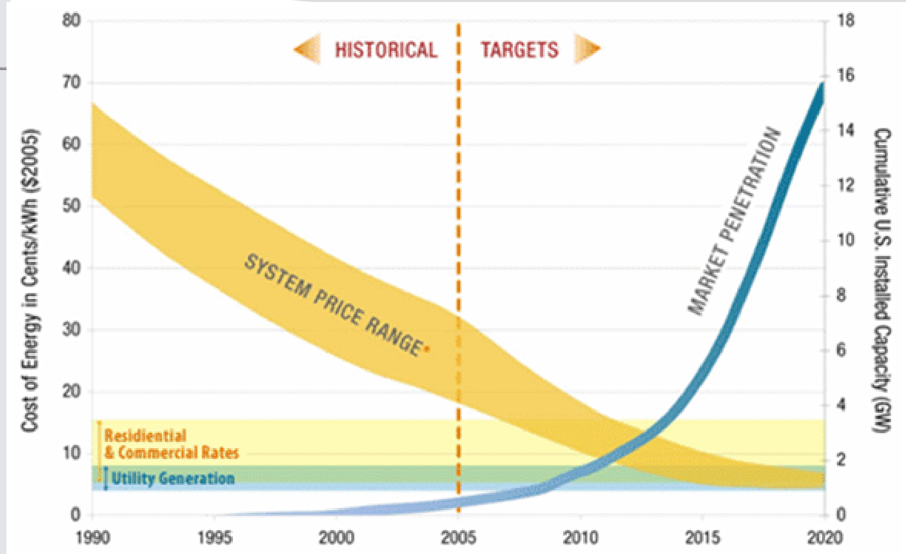
- Is it necessary to conduct a stochastic economic dispatch for the ***(near-)*** **real-time operation**?
- How to formulate a stochastic look-ahead economic dispatch?
- How to decide when and where in the horizon to apply stochastic programming?
- How to implement an efficient algorithm for real-time operations?

Increasing Renewable Penetration

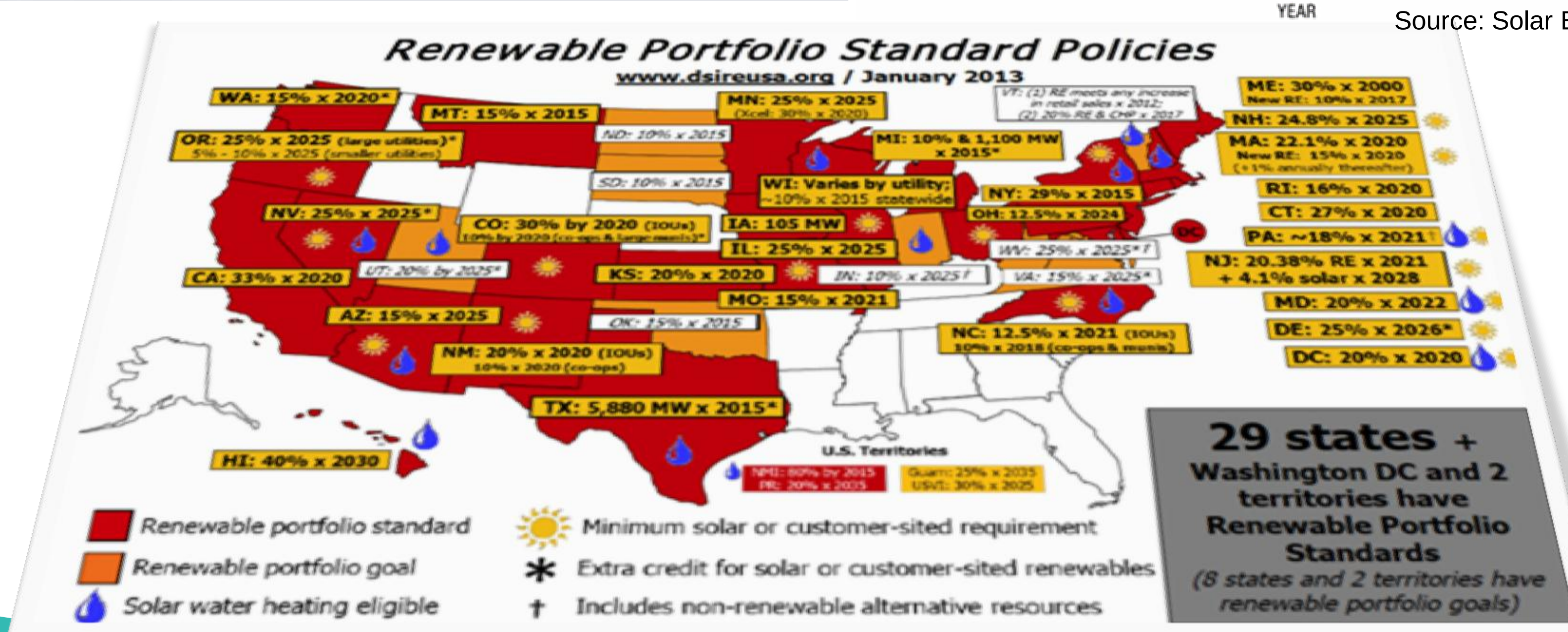
WIND POWER

Source: The global status of renewable energy

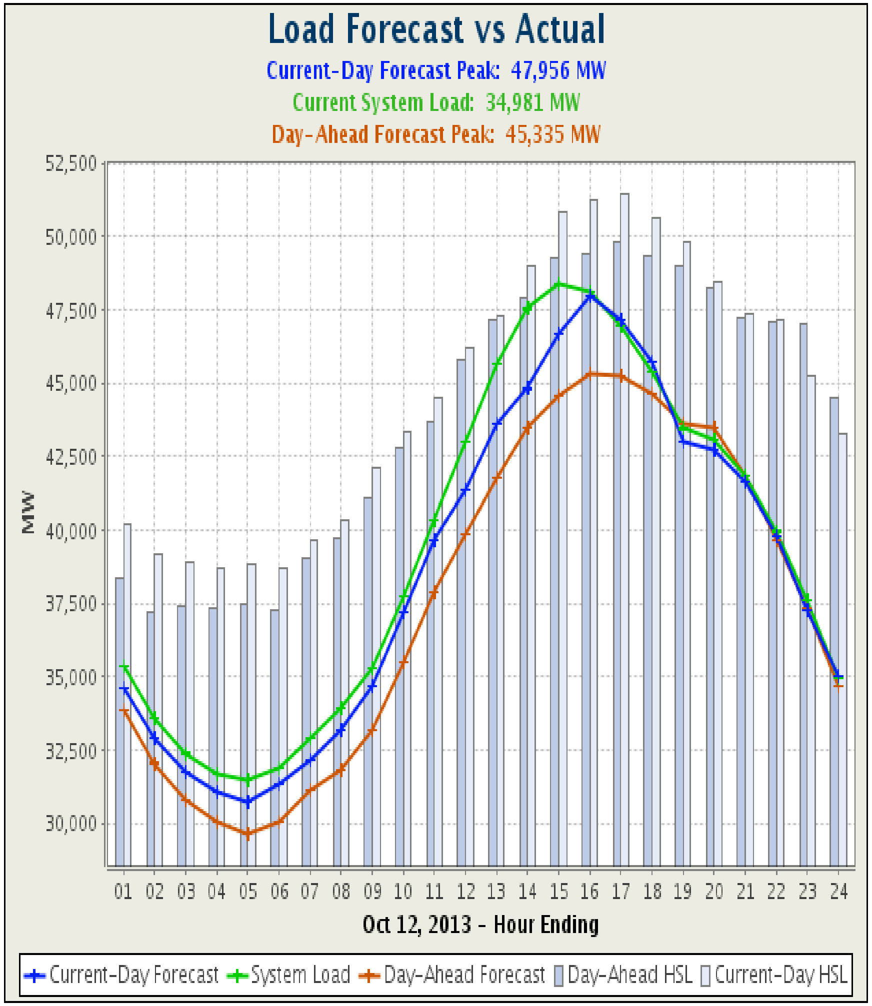


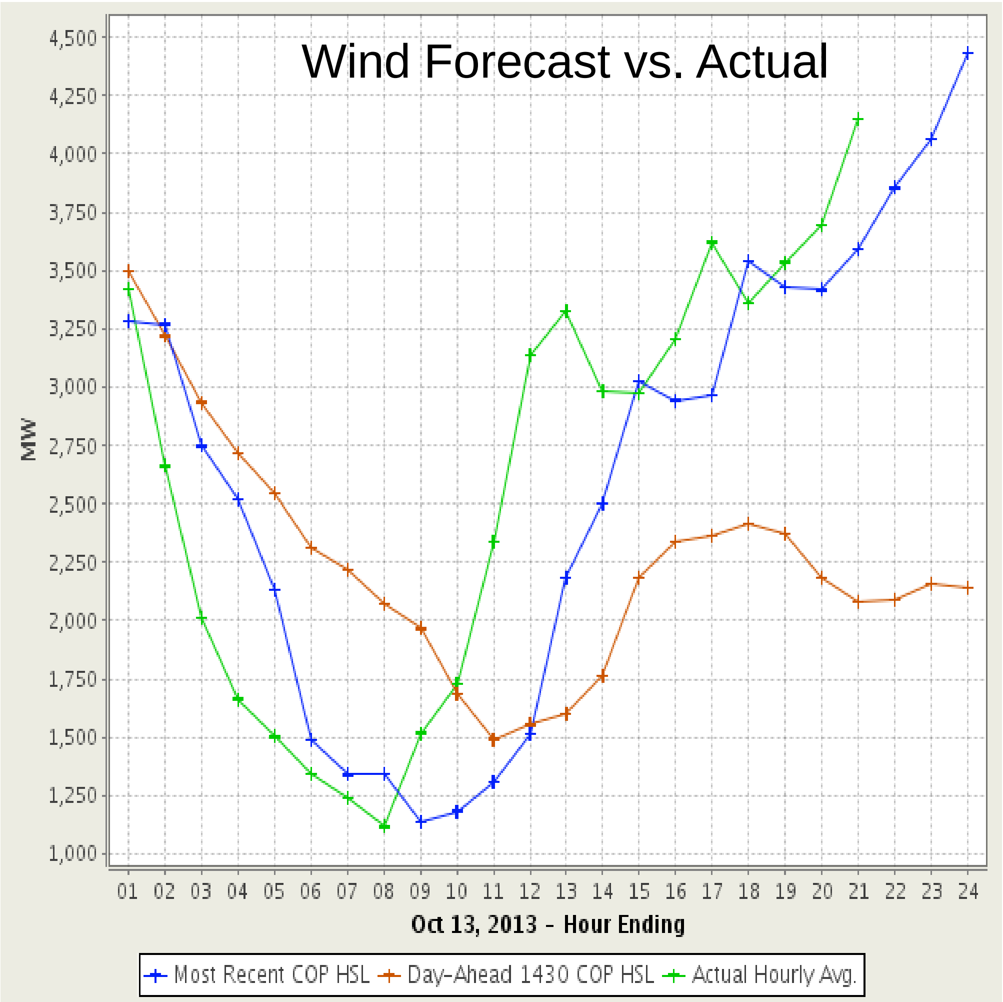


Source: Solar Energy News



Challenge of Uncertainty





Source: ERCOT Grid Information

Stochastic Programming

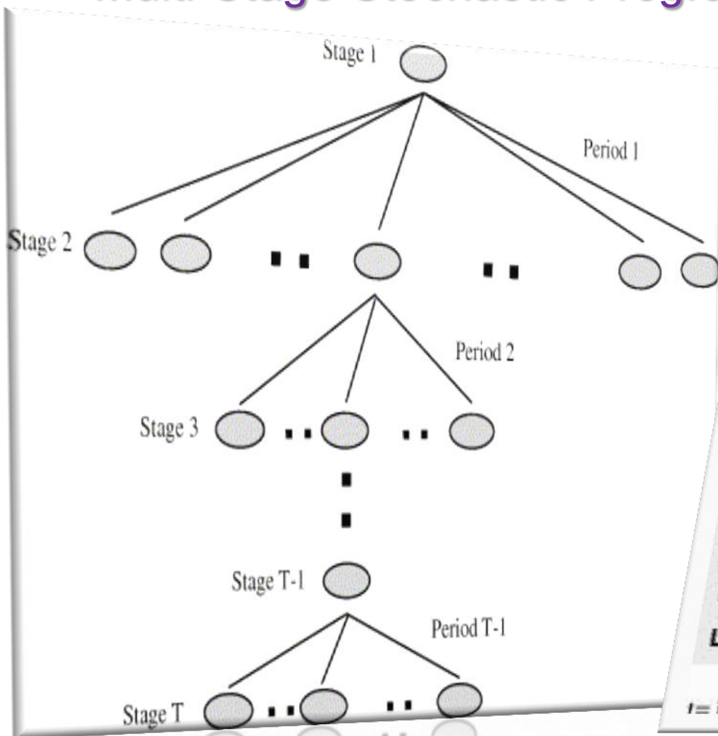
[Birge, et. al., 2011]

$$\text{minimize} \quad c \cdot x_s$$
$$\text{subject to: } x_s \in Q_s$$

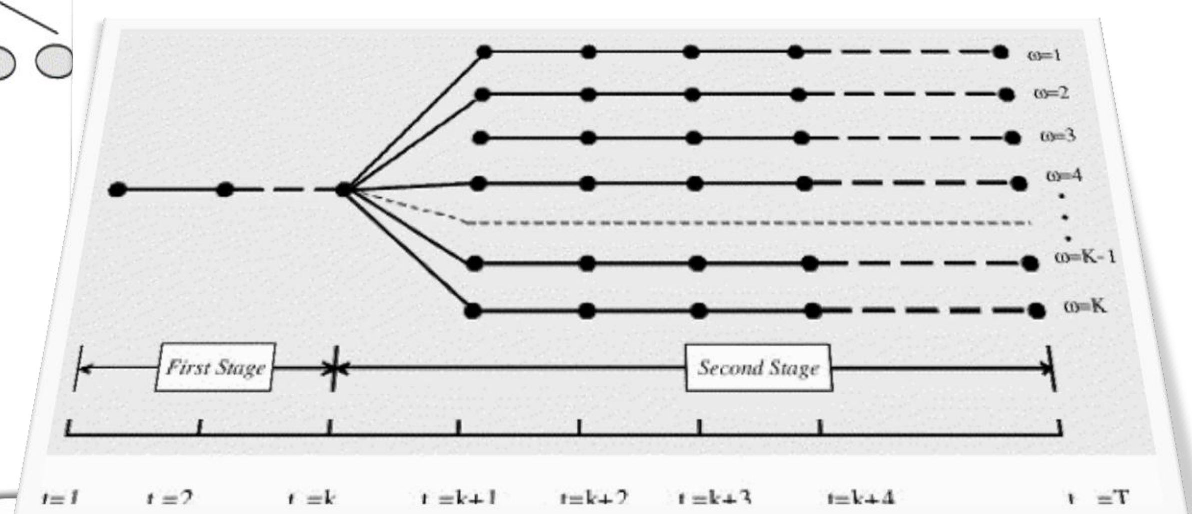
Stochastic Programming Problem

$$\text{minimize} \;\; (c \cdot x) + \sum_{s \in S} \Pr(s)(f_s \cdot y_s) \quad \text{(EF)}$$
$$\text{subject to: } \; (x, y_s) \in Q_s \quad \forall s \in S$$

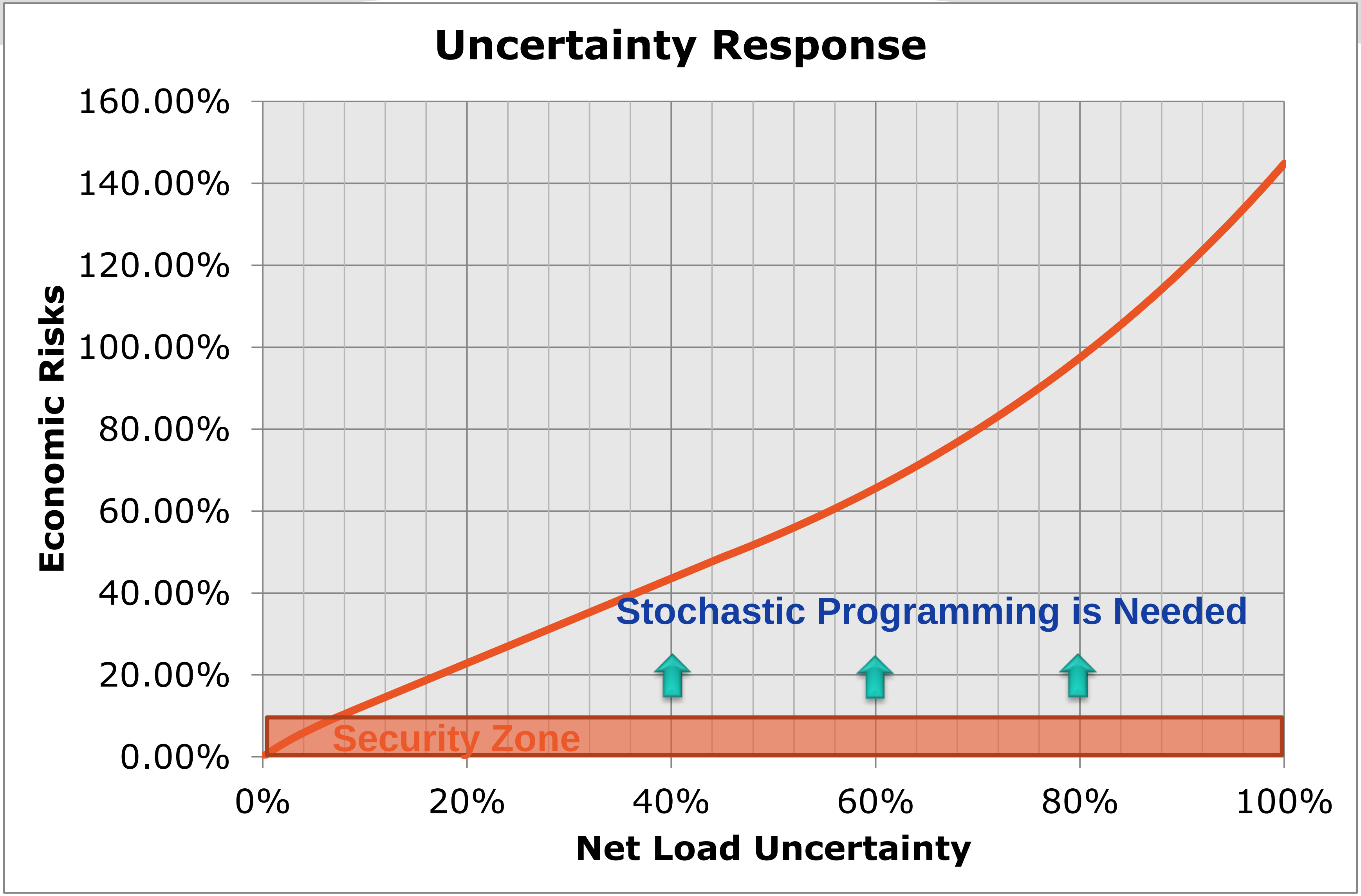
Multi-Stage Stochastic Programming



Two-Stage Stochastic Programming



Necessary Condition



Dynamic Look Ahead Scheduling

Conventional Power System Scheduling (Economic Dispatch):

Source: [Xie et. al., 2011]

$$\min \sum \text{generation cost}$$

s.t.

system security constraints.

Dynamic Look-ahead Scheduling:

$$\min \sum \sum \text{generation cost } \boxed{\text{over a look-ahead window}}$$

s.t.

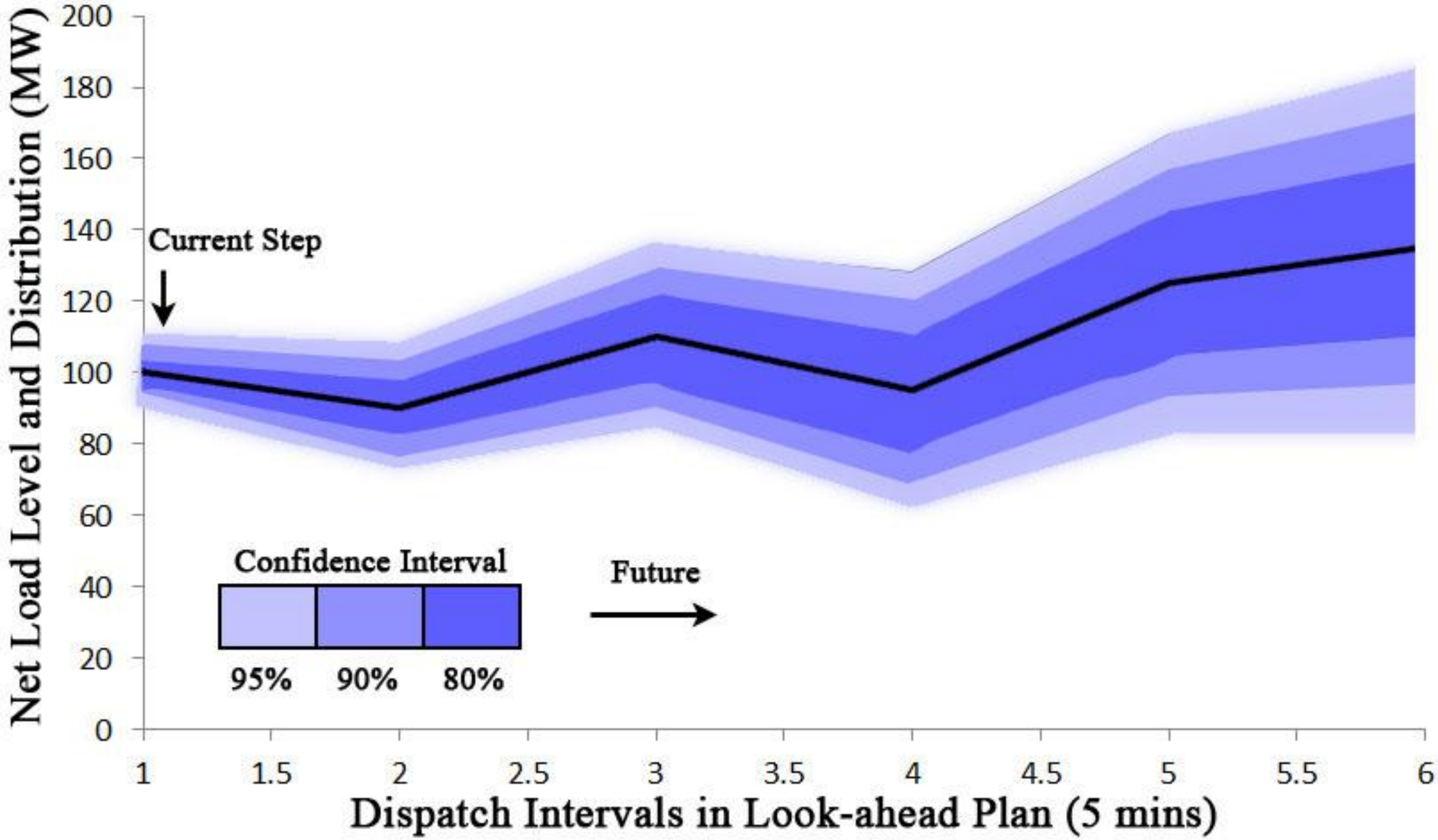
system security constraints $\boxed{\text{at each stage.}}$

$\boxed{\text{Multi-stage ramping constraints.}}$

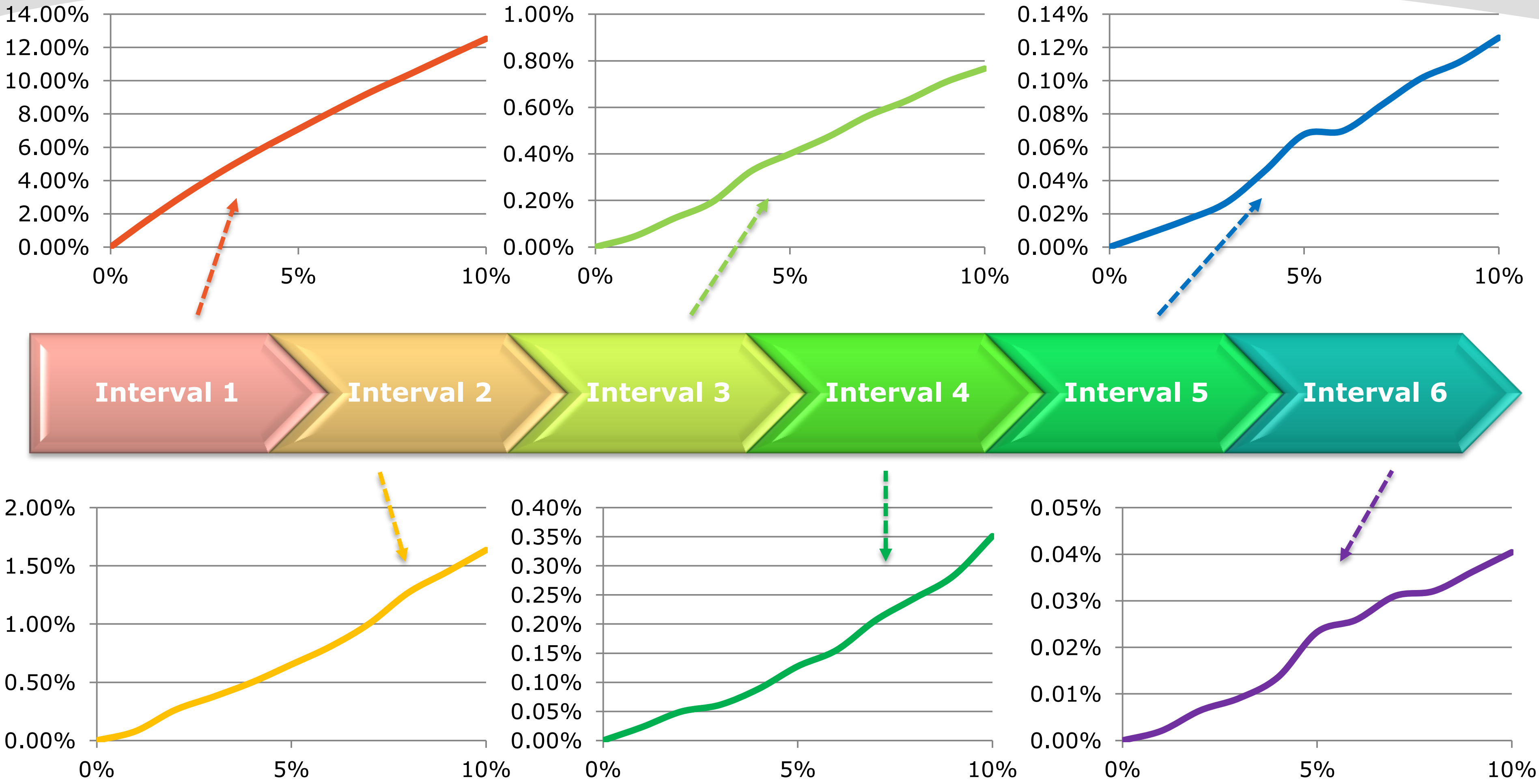
Detailed Mathematical Formulation

Look-ahead Operation Horizon

Source: [Gu et. al., 2012]



Uncertainty Responses over Horizon



Although the uncertainties in the longer run are higher, their impacts on system economic risks behave much smaller than in the shorter run.

Mathematical Criterion

Whether to do SLAED? horizon division?

Mathematical Criterion

$$Risk_{total} \approx \sum_{k}^{T} \beta_k Risk_k$$

Wind Uncertainty

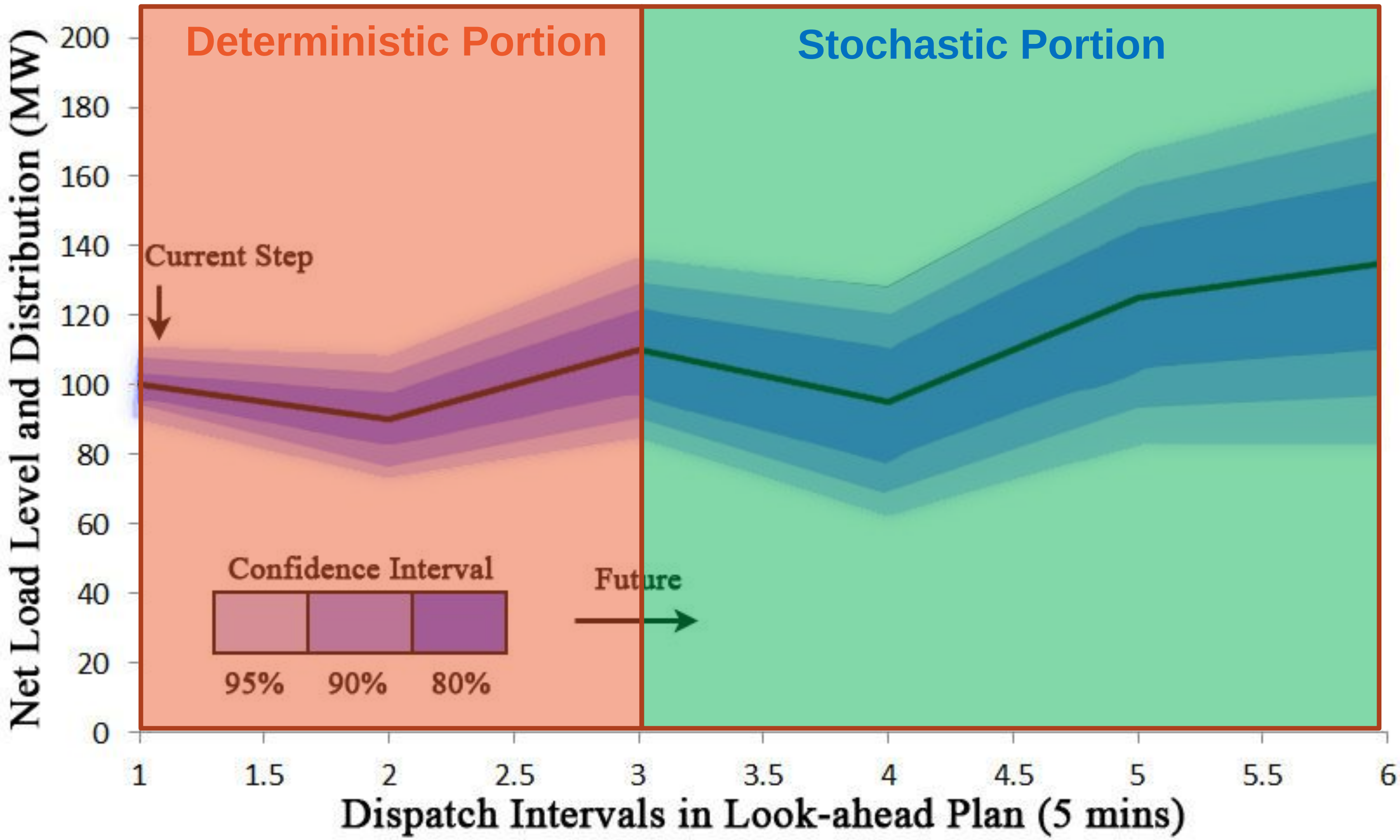
Solar Uncertainty

Load Uncertainty

Contingency Uncertainty

SLAED: Stochastic Look-ahead Economic Dispatch
β_k: Adjustment weighting factors

Hybrid Deterministic and Stochastic Horizon



Stochastic Look Ahead Dispatch

$$\min: f = \sum_{k\in T_I}\sum_{i\in G} C_{G_{i,s_0}} P_{i,s_0}^k + \sum_{s\in S}\rho_s\left[\sum_{k\in T_{II}}\sum_{i\in G} C_{G_{i,s}} P_{i,s}^k + R_s^k\right]$$

Objective Function

$$\sum_{i\in G} P_{i,s}^k = L_s^k, k\in T_I\cup T_{II}, s\in S\cup\{s_0\}$$

Energy Balancing Equations

$$\sum_{i\in G} P_{SU_{i,s}}^k \geqslant SU_s^k, k\in T_I\cup T_{II}, s\in S\cup\{s_0\}$$

$$\sum_{i\in G} P_{SD_{i,s}}^k \geqslant SD_s^k, k\in T_I\cup T_{II}, s\in S\cup\{s_0\}$$

Upward/Downward Short Term Dispatchable Capacity (STDC) Requirement

$$-\boldsymbol{F}_{\boldsymbol{s}}^{\boldsymbol{k}\max} \leqslant \boldsymbol{F}_{\boldsymbol{s}}^{k} \leqslant \boldsymbol{F}_{\boldsymbol{s}}^{\boldsymbol{k}\max}, k\in T_I\cup T_{II}, s\in S\cup\{s_0\}$$

Branch Flow Constraints

$$-P_{D_i}^R \leqslant \frac{(P_{i,s}^k - P_{i,s}^{k-1})}{\Delta T} \leqslant P_{U_i}^R, i\in G, s\in S\cup\{s_0\}, k\in T_I\cup T_{II}$$

Generators' Ramping Constraints

$$P_{i,s}^k + P_{SU_{i,s}}^k \leqslant P_{i,s}^{\max},\ i\in G, s\in S\cup\{s_0\}, k\in T_I\cup T_{II}$$

$$P_{i,s}^k - P_{SD_{i,s}}^k \geqslant P_{i,s}^{\min},\ i\in G, s\in S\cup\{s_0\}, k\in T_I\cup T_{II}$$

Generators' Capacity Constraints

$$P_{i,s}^{\min} \leqslant P_{i,s}^k \leqslant P_{i,s}^{\max}, s\in S\cup\{s_0\}, k\in T_I\cup T_{II}$$

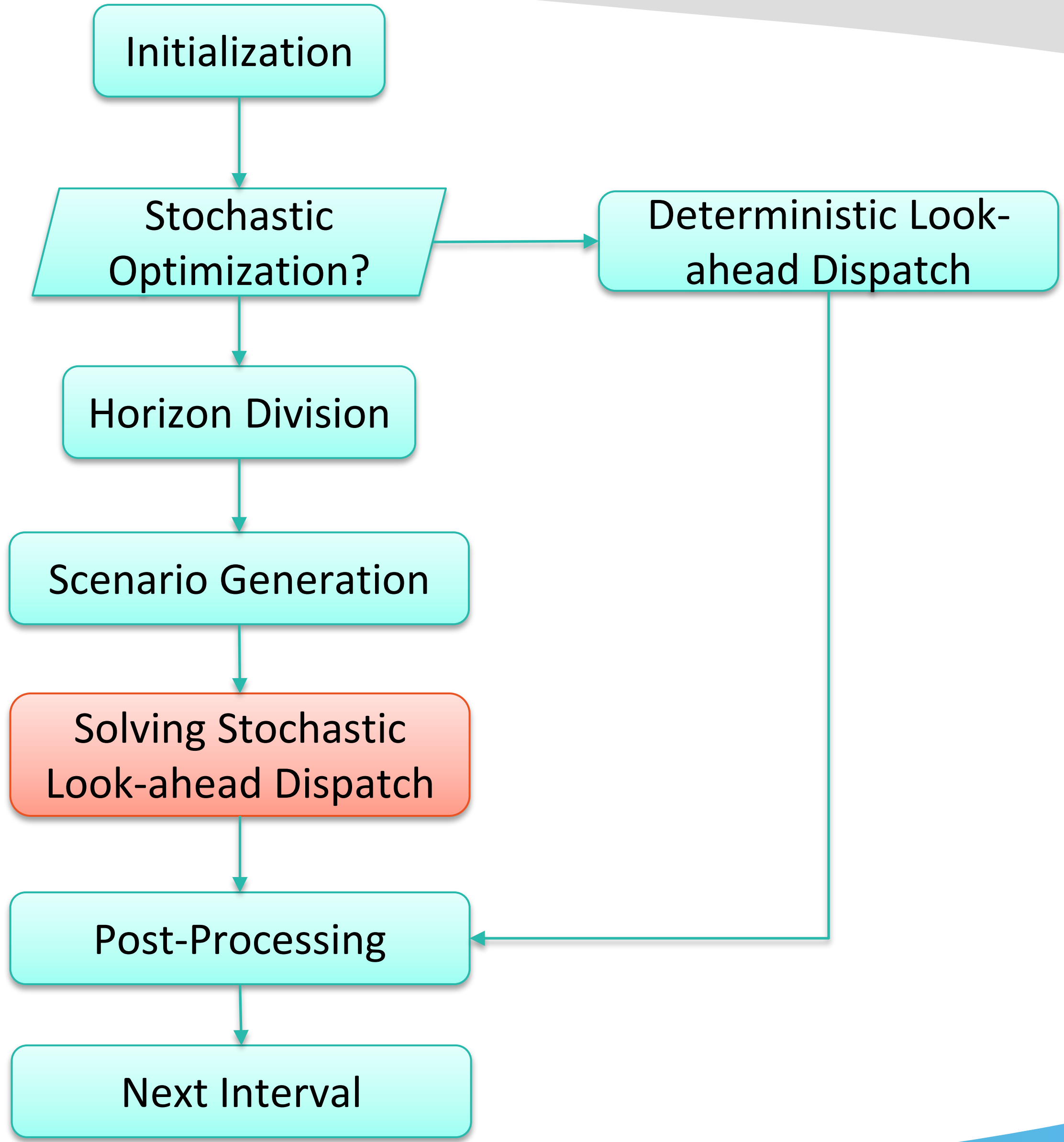
Generators' Output Constraints

$$0 \leqslant P_{SU_{i,s}}^k \leqslant P_{Ui}^R \Delta T, s\in S\cup\{s_0\}, k\in T_I\cup T_{II}$$

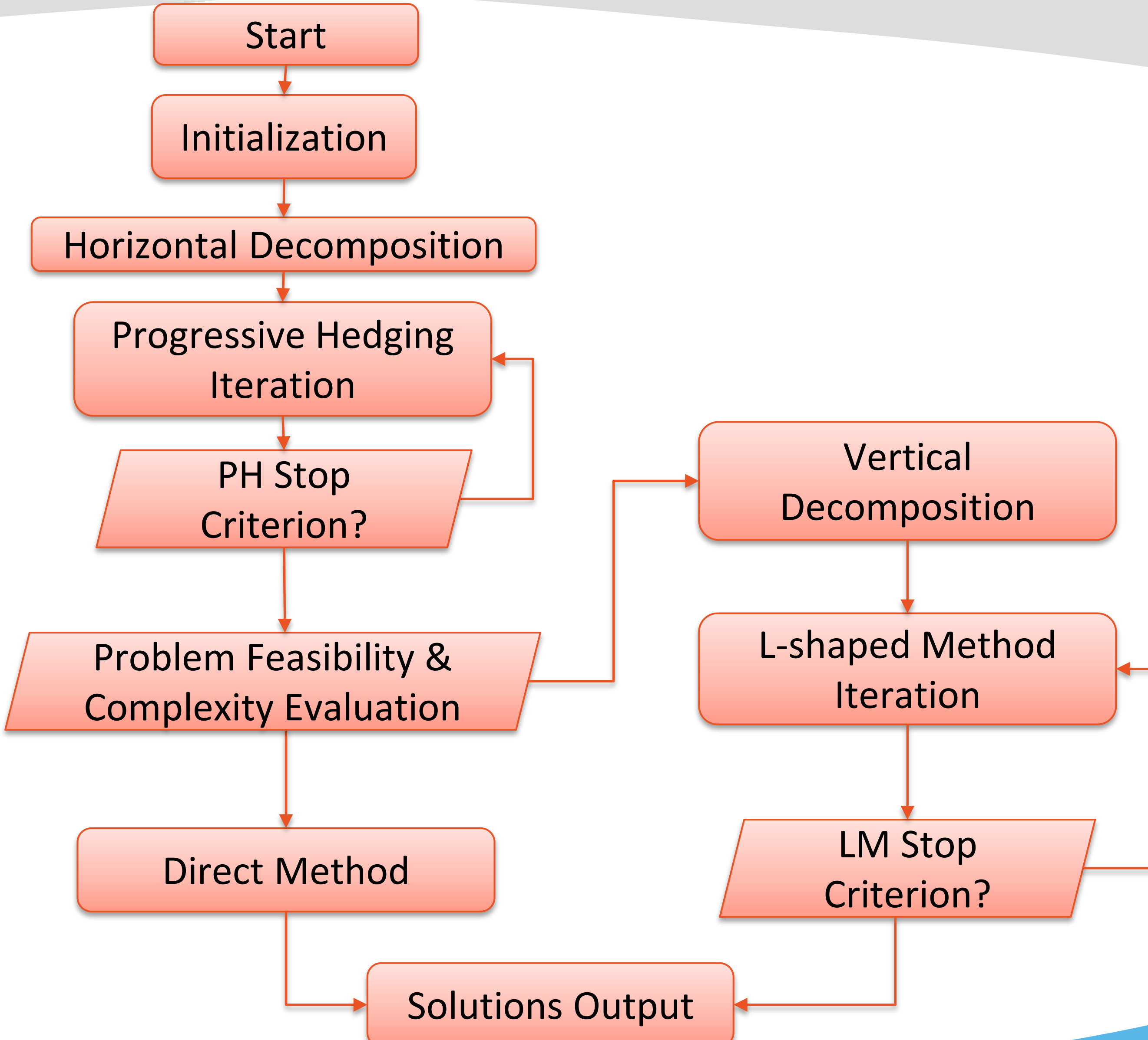
$$0 \leqslant P_{SD_{i,s}}^k \leqslant P_{Di}^D \Delta T, s\in S\cup\{s_0\}, k\in T_I\cup T_{II}$$

Upward/downward Generators' STDC

Flowchart

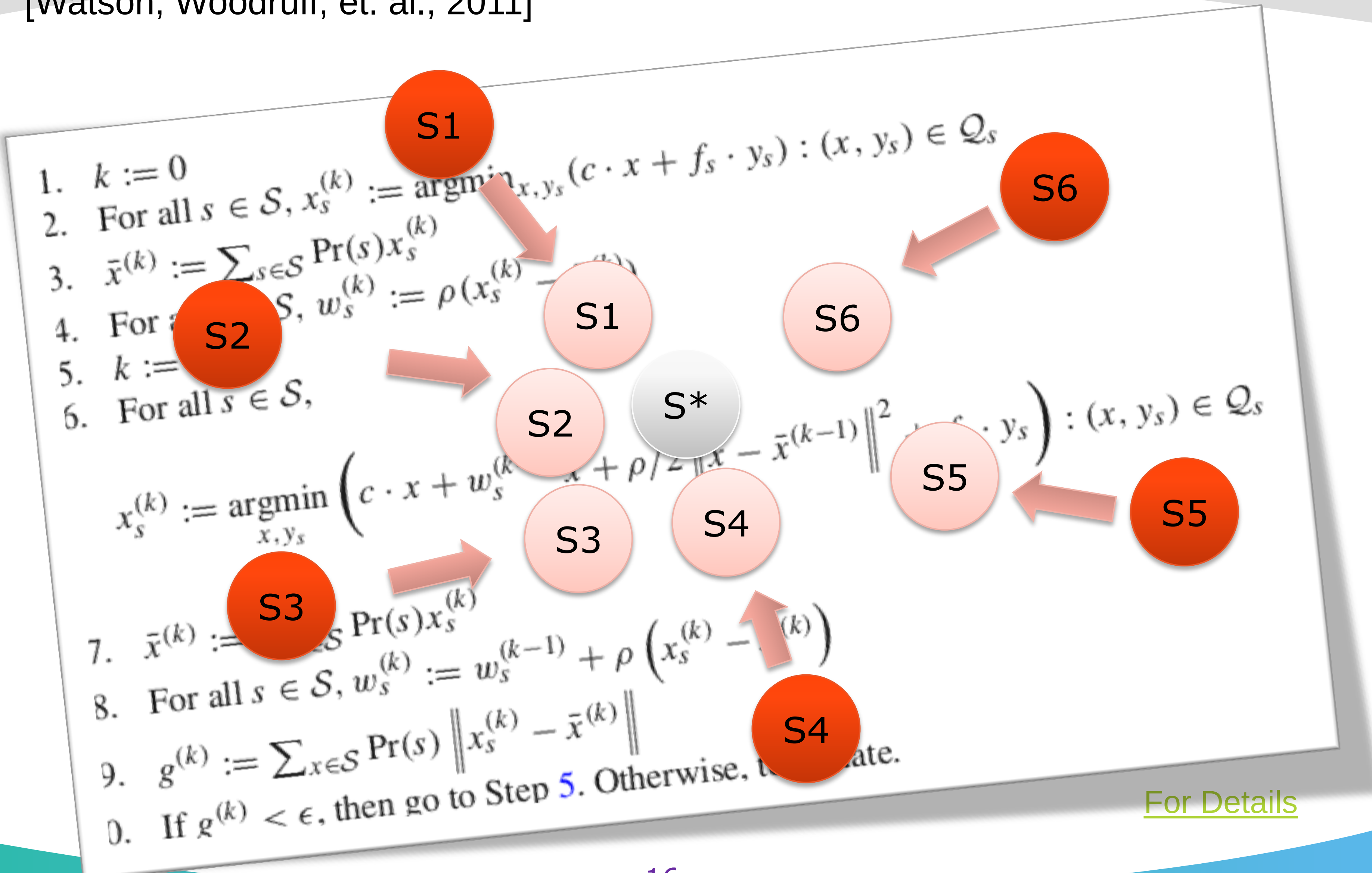

Initialization
Stochastic Optimization?
Deterministic Look-ahead Dispatch
Horizon Division
Scenario Generation
Solving Stochastic Look-ahead Dispatch
Post-Processing
Next Interval

Computation Framework Flowchart



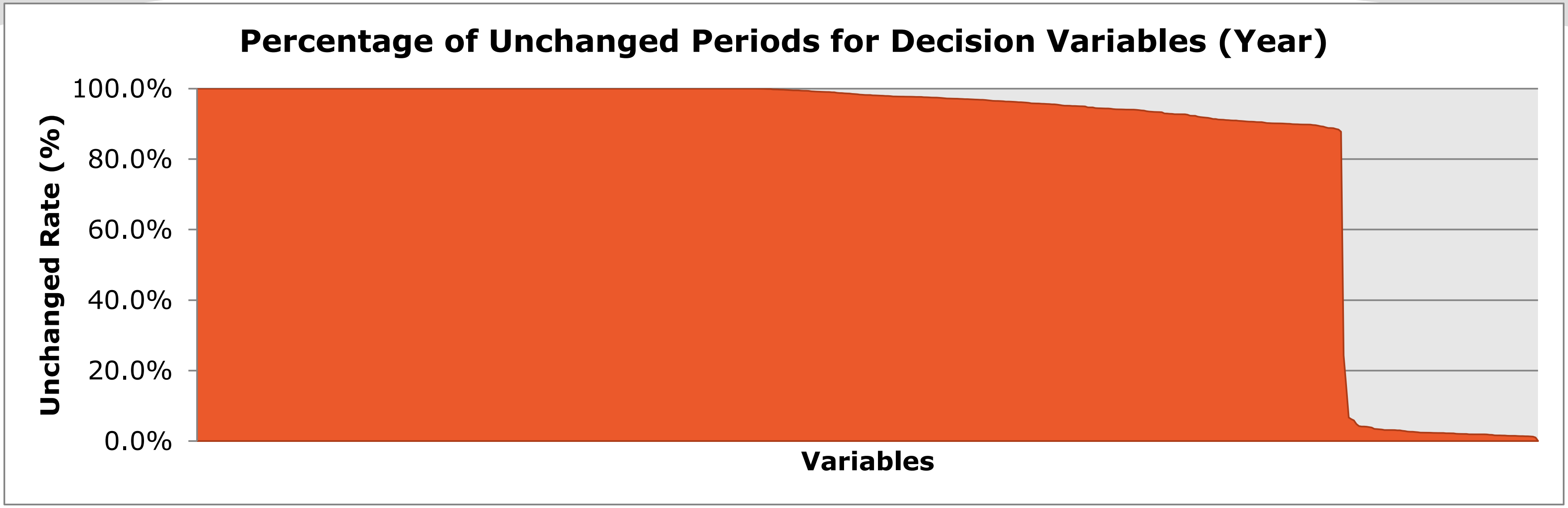
Progressive Hedging Algorithm

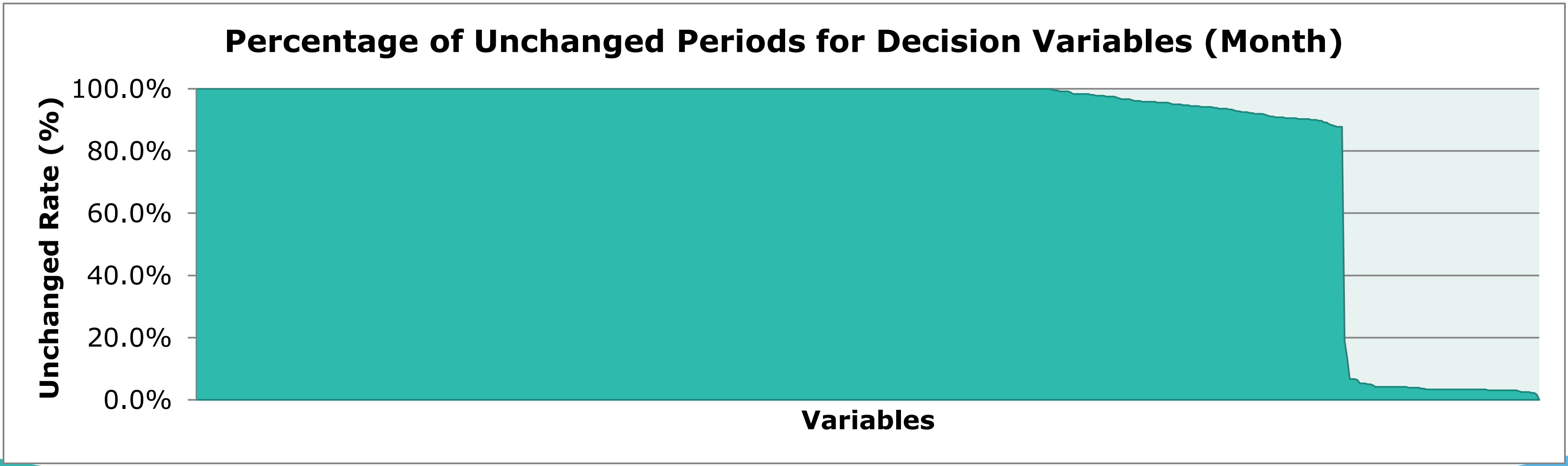
[Watson, Woodruff, et. al., 2011]



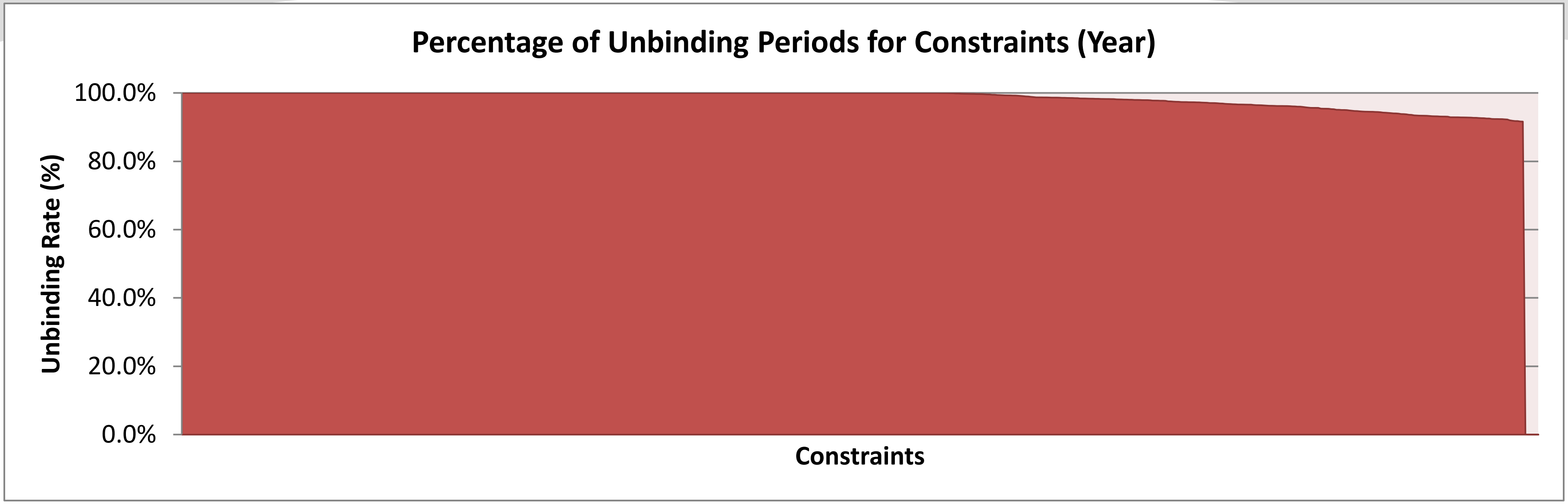
For Details

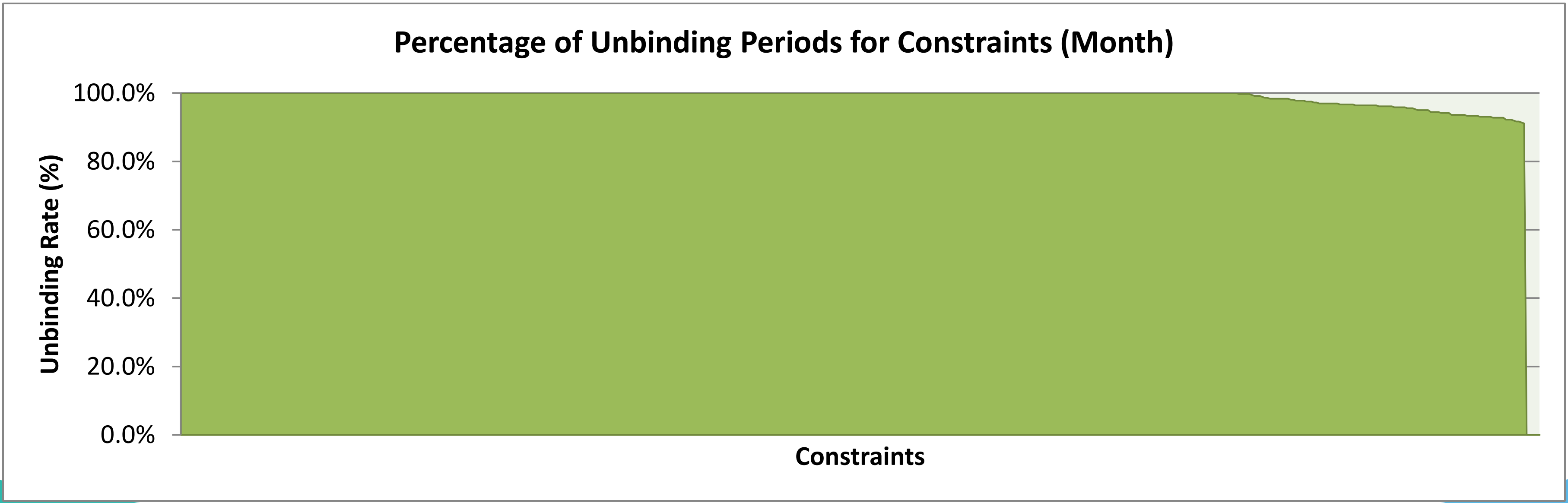
Variable Fixing





Constraints Removal





Variable Fixing and Constraints Removal

$$\min : f_{TC} = \sum_i x_i T_{vi} + \sum_j y_j T_{cj}$$

Minimize the computation time

Subject to

$$\sum_i x_i \lg P_{vi} \ge \lg\left(1 - C_v\right)$$

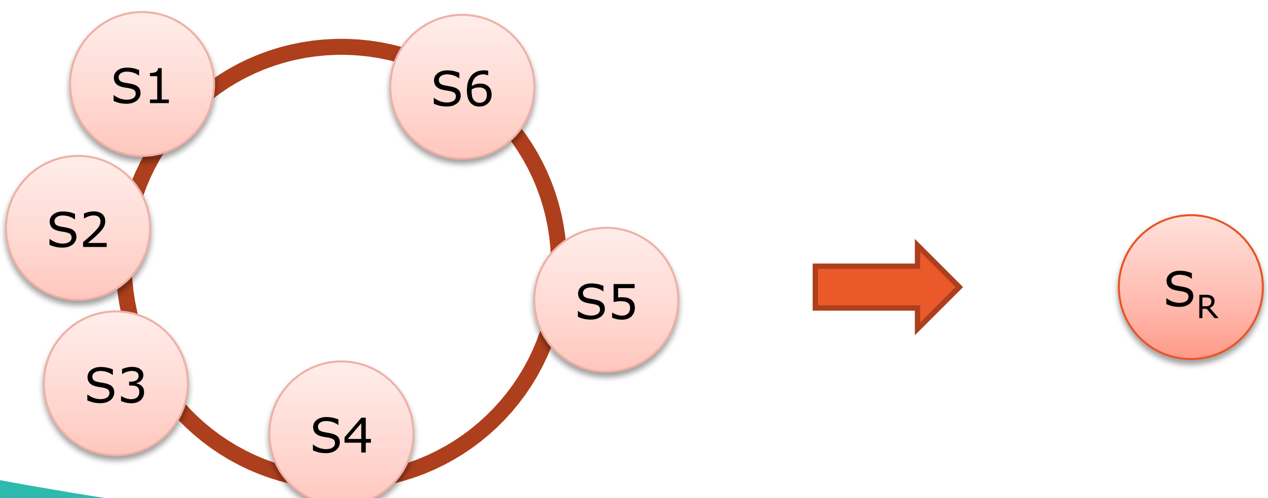
Probability Requirement for Variable Fixing

$$\sum_j y_j \lg P_{cj} \ge \lg\left(1 - C_c\right)$$

Probability Requirement for Constraints Removal

$$x_i \in \{0,1\}, y_i \in \{0,1\}$$

Decision Variables' self-constraints



One extensive form with much reduced size.

L-shaped Method

[Slyke, Wets, et. al., 1969]

We give the name *L-shaped linear programs* to linear programs of the form: Minimize

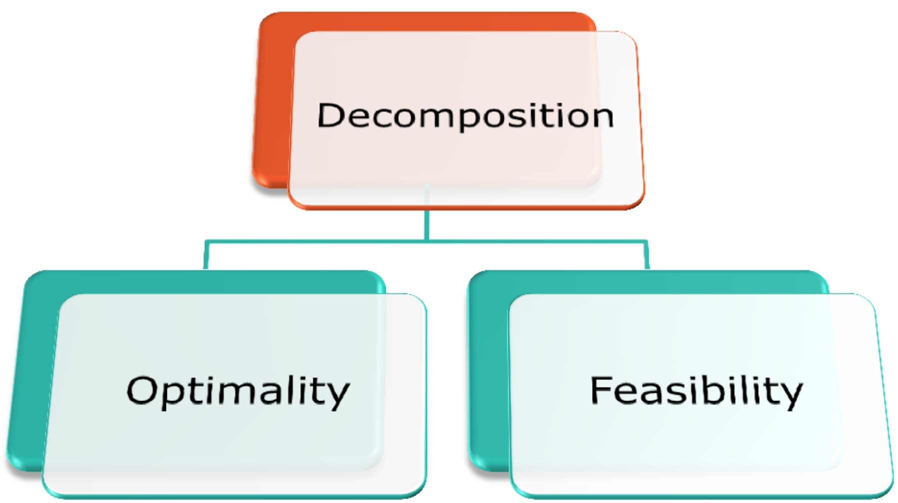
(1) $$z = c^1 x + c^2 y$$

subject to

(1a) $$A^{11} x \qquad\qquad = b^1,$$

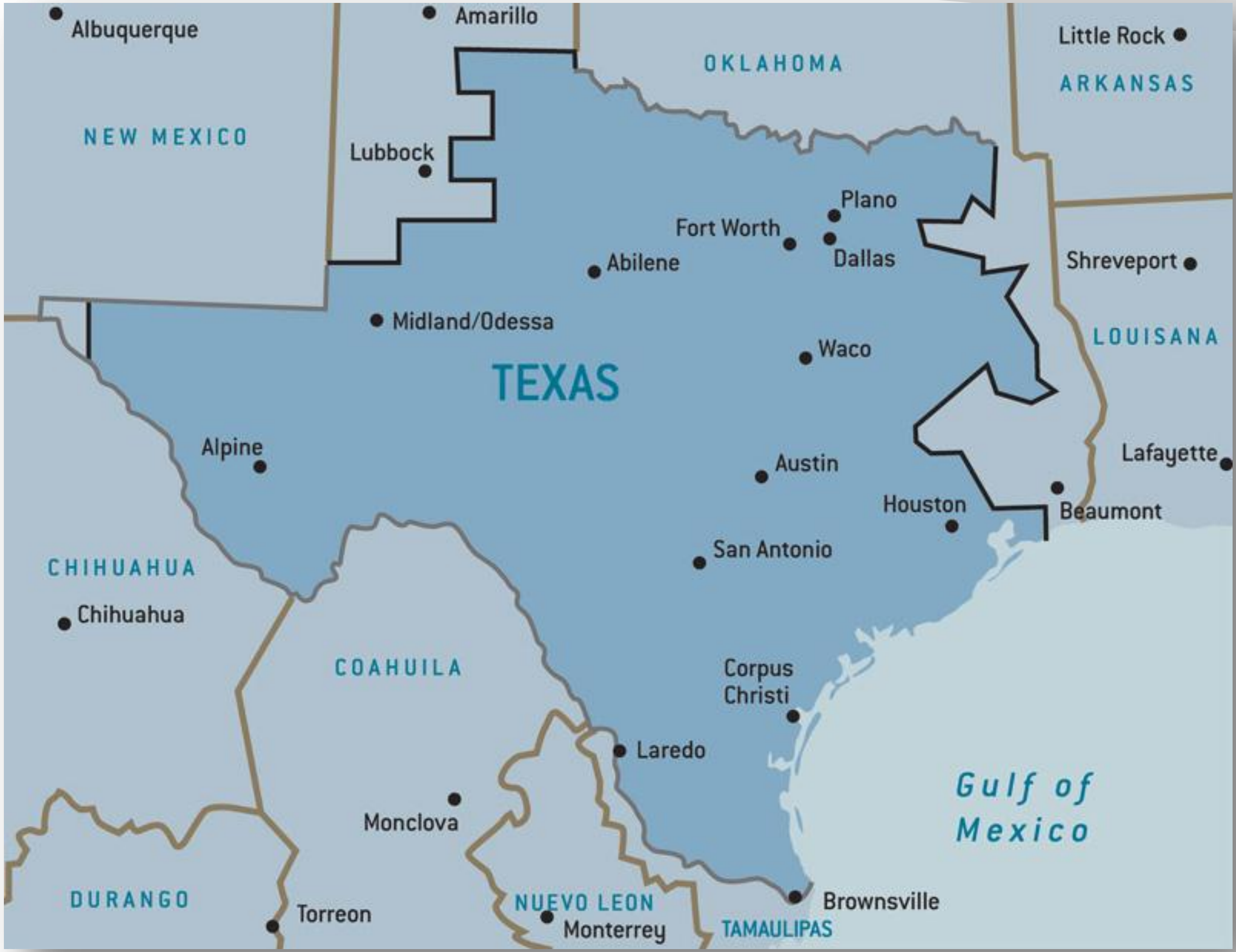
(1b) $$A^{21} x + A^{22} y = b^2,$$

$$x \geqq 0, \qquad y \geqq 0,$$



Numerical Experiments

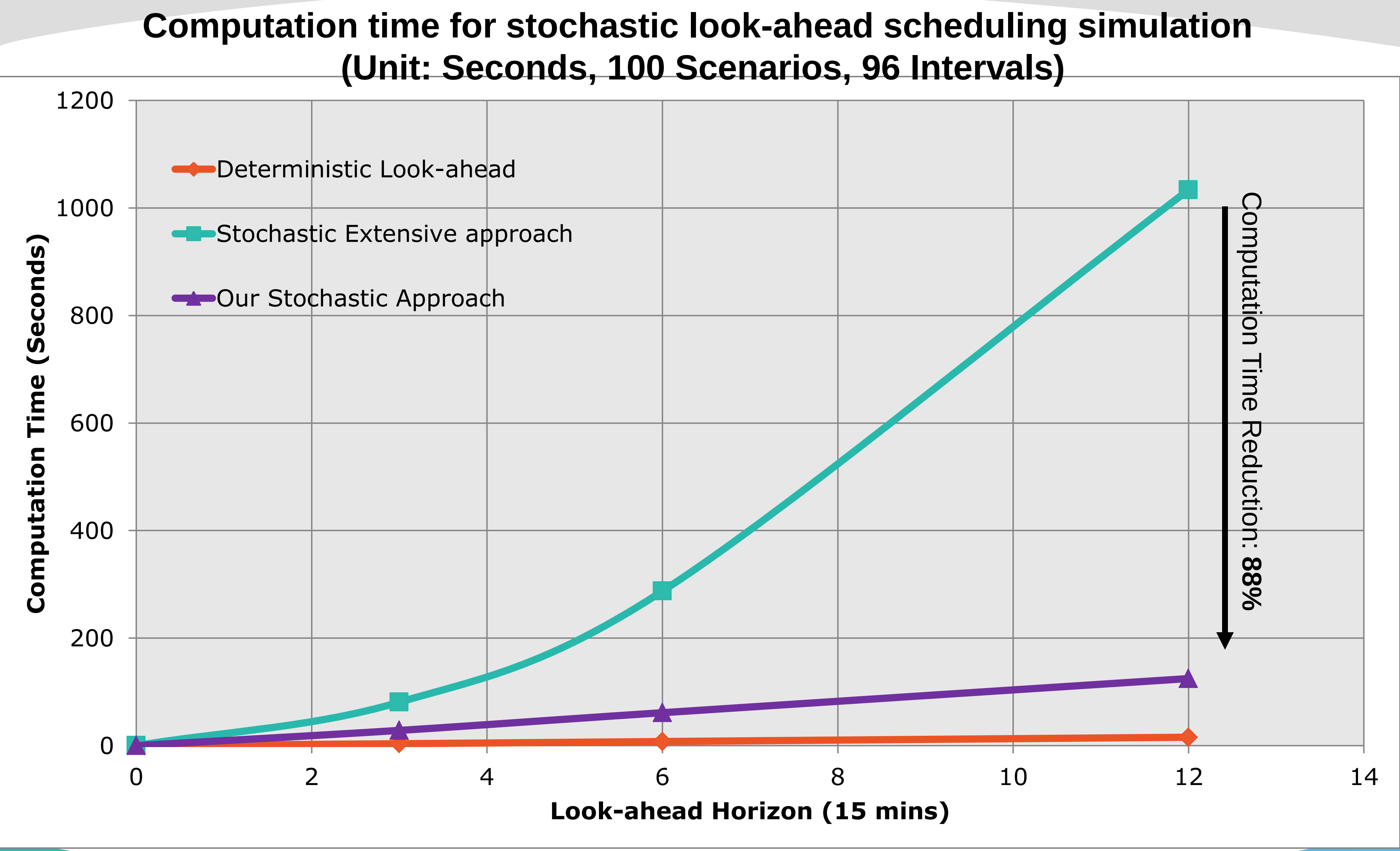
ERCOT System



Source: ERCOT.com

5889 Buses;
7220 Branches;
523 Power Plants;
76 Aggregated Wind Farms;
9710.4 MW Installed Wind Capacity;
Represent 85% of Texas Demand.

Numerical Experiments



Numerical Experiments

Problem Formulation Size for Look-ahead Scheduling

Look-ahead Horizon	45 mins	90 mins	180 mins
Deterministic Look-ahead Scheduling	5028 X 25707	10056 X 51414	20169 X 102828
Stochastic Look-ahead Scheduling (Extensive approach)	36454 X 188468	72908 X 376936	177299 X 753872
Stochastic Look-ahead Scheduling (Enhanced PH)*	3776 X 11472	6504 X 26376	8568 X 44776
% of Original Problem Size (Row 2)	0.63%	0.62%	0.28%

* For enhanced PH, the original formulation has the same size as extensive approach does. What is shown is the size of the final reduced form.

Summary

- We developed a stochastic look-ahead dispatch framework for (near)-real-time operation
- We proposed a data driven criterion for stochastic programming applicability and horizontal partition.
- We designed enhanced hybrid computational framework of progressive hedging and L-shaped method for efficient & parallel computation.
- **Future work:**
- LMP studies under stochastic economic dispatch

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Thank You !

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Questions and Answers